LOCATION AND SUCCESS OF LESSER PRAIRIE-CHICKEN NESTS IN RELATION TO VEGETATION AND HUMAN DISTURBANCE

JAMES C. PITMAN,[1,2] Division of Biology, Kansas State University, Manhattan, KS 66506-4901, USA
CHRISTIAN A. HAGEN,[3] Division of Biology, Kansas State University, Manhattan, KS 66506-4901, USA
ROBERT J. ROBEL, Division of Biology, Kansas State University, Manhattan, KS 66506-4901, USA
THOMAS M. LOUGHIN, Department of Statistics, Kansas State University, Manhattan, KS 66506-0802, USA
ROGER D. APPLEGATE,[4] Kansas Department of Wildlife and Parks, P.O. Box 1525, Emporia, KS 66801-1525, USA

Abstract: Lesser prairie-chicken (*Tympanuchus pallidicinctus*) populations have declined rangewide, and one of the principal causes is thought to be low nest success. Little is known about the relationship of vegetation structure and human intrusion to lesser prairie-chicken nest location and success. We conducted our study from 1997 to 2002 in southwestern Kansas, USA, on 2 sand-sagebrush (*Artemisia filifolia*) prairie areas managed for livestock production. We determined apparent nest success (26%) for 200 of 209 lesser prairie-chicken nests located. Nest sites had taller grass, greater sand-sagebrush density, and higher visual obstruction than random locations in the surrounding prairie. We recorded the distances from nests to 6 anthropogenic features (wellheads, buildings, improved roads, unimproved roads, transmission lines, center-pivot irrigation fields) to determine whether the features were related to nest location and success. Sand-sagebrush habitat around 5 of 6 features (all except unimproved roads) was avoided for 80 m (wellheads) to >1,000 m (buildings) by nesting lesser prairie-chickens, but distances to the features were not substantial predictors of apparent nest success. Grass height, sagebrush plant density, and sagebrush height were the most important vegetation characteristics influencing nest success.

JOURNAL OF WILDLIFE MANAGEMENT 69(3):1259–1269; 2005

Key words: anthropogenic impacts, *Artemisia filifolia*, Kansas, lesser prairie-chicken, nest vegetation, nest success, sand-sagebrush, *Tympanuchus pallidicinctus*.

Lesser prairie-chickens occupy xeric grasslands dominated by sand-sagebrush or shinnery oak (*Quercus havardii*) in portions of southwestern Kansas, southeastern Colorado, western Oklahoma, northern Texas, and eastern New Mexico, USA (Giesen 1998). Their numbers have declined rangewide since the 1800s (Braun et al. 1994). In Kansas, lesser prairie-chickens are most abundant south of the Arkansas River in mixed- and short-grass-prairie that is dominated by sand-sagebrush, but annual counts of leks and individual birds suggest their abundance has declined since the 1970s (Jensen et al. 2000). Most of the decline has been attributed to habitat deterioration and conversion to intensive row crop agriculture. Even though large-scale conversion of sand-sagebrush prairie to intensive agriculture all but ceased in the mid 1980s, indices of lesser prairie-chicken populations continued to decline (Jensen et al. 2000).

Historically, the portion of Finney County, Kansas, that lies south of the Arkansas River was sand-sagebrush prairie that supported a viable lesser prairie-chicken population (R. D. Rodgers, Kansas Department of Wildlife and Parks [KDWP], personal communication). Between 1960 and 1975, approximately 60% of the native sand-sagebrush prairie in the county was converted to row crops, primarily center-pivot irrigated corn and alfalfa (Sexson 1980). Human population in the county has grown by over 25% within the last 2 decades (U.S. Census Bureau 2003). This growth coincides with construction of a coal-fired, electric generating station and associated transmission lines, road improvements, and housing development in rural settings. Petroleum exploration and production have increased in the county, and compressor stations have been constructed to enhance movement of natural gas through underground pipelines. Continued decline of lesser prairie-chicken populations in Finney County over the last 20 years (R. D. Rodgers, KDWP, personal communication) coincides with these anthropogenic changes. Sand-sagebrush prairie fragments >5,000 ha remain in the county and are grazed at various intensities by livestock, resulting in highly variable vegetation structure.

Nest success is a critical demographic parameter regulating prairie grouse populations (Peterson and Silvy 1996, Wisdom and Mills 1997, Hagen 2003). We were unable to locate any pub-

[1] Present address: Indiana Division of Fish and Wildlife, 4112 State Road 225 East, West Lafayette, IN 47906, USA.
[2] E-mail: jpitman@dnr.in.gov
[3] Present address: Oregon Department of Fish and Wildlife, 61374 Parallel Road, Bend, OR 97702, USA.
[4] Present address: Tennessee Wildlife Resource Agency, Ellington Agricultural Center, P.O. Box 40747, Nashville, TN 37204.

lished data that documented the relationship between vegetation structure and location or success of lesser prairie-chicken nests in sand-sagebrush prairie. Giesen (1994) reported vegetation structure at lesser prairie-chicken nest sites in sand-sagebrush prairie in Colorado, but he did not draw comparisons between vegetation structure at successful and unsuccessful nests or nests and random locations. Additionally, only Lyon and Anderson (2003) examined the impacts of anthropogenic features (transmission lines) on greater sage-grouse (*Centrocercus urophasianus*) nest site location. Impact of transmission lines or other anthropogenic features on locations of prairie grouse nests has never been reported elsewhere. Thus, our objective was to evaluate lesser prairie-chicken nest-site location and success in relation to vegetation structure and 6 prominent anthropogenic features (buildings, improved roads, unimproved roads, transmission lines, gas and oil wellheads, center-pivot irrigated fields) in sand-sagebrush prairie of Finney County.

STUDY AREA

We conducted this research in sand-sagebrush prairie south of Garden City, Kansas (37°52N, 100°59W), from spring 1997 through summer 2002 in 2 phases. We initiated phase I on a 7,700-ha, sand-sagebrush prairie area (Area I) in 1997, and we started phase II on a nearby 5,600-ha prairie area (Area II) in 2000; we continued work on both areas through summer 2002. Each area was bounded almost entirely by center-pivot irrigated cropland and grazed seasonally by livestock. Improved and unimproved roads, oil and gas wellheads, transmission lines, and buildings (e.g., houses, compressor stations, etc.) were present on each area.

Sand-sagebrush was the most prominent vegetation on the 2 areas. Primary grasses were little bluestem (*Schizachyrium scoparium*), needle-and-thread grass (*Stipa comata*), sand lovegrass (*Eragrostis trichodes*), six-weeks fescue (*Vulpia octaflora*), blue grama (*Bouteloua gracilis*), sideoats grama (*B. curtipendula*), sand dropseed (*Sporobolus cryptandrus*), and western wheatgrass (*Agropyron smithii*). The most common forb species were Russian-thistle (*Salsola kali*), western ragweed (*Ambrosia psilostachya*), sand lilly (*Nuttalia nuda*), and common sunflower (*Helianthus annuus*; Hulett et al. 1988). Plains prickly-pear cactus (*Opuntia polyacantha*) and plains yucca (*Yucca glauca*) were common in disturbed areas. Plant nomenclature follows McGregor et al. (1976). Annual precipitation averaged 50 cm (U.S. Department of Commerce 2003) and ranged from 42 cm (2000) to 59 cm (1997).

METHODS

Locating and Monitoring Nests

We captured female lesser prairie-chickens on leks using walk-in funnel traps (Haukos et al. 1990). We fitted each captured bird with an 11-g, necklace-style transmitter, and we released each bird on-site immediately after capture. Capture and handling procedures were approved by the Animal Care and Use Committee at Kansas State University (ACUC no.2609). We determined locations of transmitter-equipped birds daily, and we found nests by approaching transmitter-equipped females when locations were unchanged for ≥3 days. We marked nest locations with flags (1997) or transmitters 5 m from the nest bowl (1998, 1999), or we recorded nest locations with a Global Positioning System (GPS; 2000–2002). We assumed females were still incubating a nest if telemetry bearings were relatively unchanged from the previous day. We did not revisit nest sites until females departed with a brood or the nest was depredated or abandoned. We used apparent nest success throughout our analyses, (i.e., [nests producing ≥1 chick/total number of nests] × 100).

Vegetation Sampling

We quantified vegetation structure at each nest site within 3 days of a hatching event, depredation event, or abandonment except in 1997 when we recorded measurements in late July. We centered 2 perpendicular, 11-m sampling transects on the nest bowl, one in a north-south orientation and the other east-west. Beginning at the nest bowl, we measured vegetation at 3 points (spaced 2 m apart) in each cardinal direction, which totaled 12 subsampling locations at each nest site. At each subsampling location, we estimated non-overlapping vegetation cover (% grass, sagebrush, and forbs) and bare ground in a 20 × 50 cm Daubenmire (1959) frame and recorded visual obstruction readings (VOR) to 0.5 dm from a distance of 2 m and a height of 0.5 m (Robel et al. 1970).

Beginning in phase II, we measured heights of the nearest grass, sagebrush plant, and forb at each nest site. Additionally, we placed an overhead cover board (16 cm in diameter) that we modified from Roersma (2001) in the nest bowl to estimate percentage of the nest obscured from overhead. We used the point-centered quarter (PCQ) method to estimate sand-sagebrush plant density (ha^{-1}) at nest sites. Our approach utilized distance to the nearest plant in each of 4 quadrants created by the sampling transects (Cottam and Curtis 1956). Additionally, we measured height and diameter of sagebrush plants nearest the nest site. We sampled vegetation at a paired random point, within an arbitrary distance of 175 m from the nest site, with the same techniques used at nests.

During the summers of 2001 and 2002, we calculated mean density, height, and diameter for stands of sand-sagebrush in 10 pastures on Area I and 15 pastures on Area II. We derived these estimates using data collected at 35 random sampling locations within each pasture.

Collecting Landscape Data

We used GPS to record locations of wellheads, buildings, transmission lines, improved and unimproved roads, and center-pivot irrigated fields on each study site. We incorporated spatial data into a Geographic Information System (GIS) of each area created in ArcView 3.1 (Environmental Systems Research Institute 1992) using a land-cover map from the Kansas GAP Analysis Program. We entered a layer containing locations of successful and unsuccessful nests into the GIS and calculated distances (m) to the nearest wellhead, building, transmission line, improved road, unimproved road, and center-pivot irrigated field edge (hereafter center-pivot field) for each nest.

For wellheads, we included oil or gas wells with pumping units powered by electric, natural gas, or diesel motors; we did not distinguish among these in our analyses. For buildings, we included human dwellings, gas compressor stations, and a 380 MW coal-fired, electric generating station. For transmission lines, we primarily included 125, 138, and 345 kV double circuit conductors that distributed electricity from the generating station, but we also included a few smaller power lines to homes and wellheads. For improved roads, we included graveled or paved roads that carried up to 486 vehicles per day (vpd), whereas for unimproved roads, we included 2-lane pasture trails and ungraded service roads to wellheads with traffic averaging <3 vpd. Center-pivot irrigated fields covered 65 ha (160 acres). Each pivot had a natural gas or diesel-powered water pump in the center and a 4- to 5-m high sprinkler boom that extended from the center to the edge of the field. The sprinklers were generally in operation from late April or early May through mid September.

Data Analysis

We combined data from both phases of our study when possible. We excluded vegetation measurements taken in 1997 from all analyses because we did not record them until well after conclusion of the nesting season. We considered most statistical tests significant at $P < 0.05$; however, we considered vegetation characteristics significant at $P < 0.10$ due to the high variability associated with these data.

Nest Success.—We used a Fisher's exact test (Agresti 2002) to compare apparent nest success between areas in individual years. We used a Cochran-Mantel-Haenszel test (Agresti 2002) to control for annual variability in pooled estimates of apparent nest success between the 2 areas. We used a Pearson chi-square test for independence (Agresti 2002) to compare overall nest success across years. We excluded abandoned nests (n = 4) from estimates of apparent nest success.

Vegetation and Nest Success.—We developed logistic regression models to predict success of 155 lesser prairie-chicken nests (113 unsuccessful and 42 successful). We excluded measurements collected at nest sites left unattended due to abandonment (n = 4) or predation of the female while away from the nest (n = 3). We developed the logistic regression models with 12 vegetation variables and nest proximity (m) to 6 anthropogenic features (oil and gas wellheads, improved roads, unimproved roads, transmission lines, buildings, and center-pivot fields). We did not consider area and year potential predictor variables initially so resulting models would have greater utility. We considered quadratic transformations for all vegetation variables, and due to the large number of variables, we used an exploratory, all-subsets modeling approach (i.e., considering all 2-way interactions) as the variable selection procedure (Agresti 2002). We used SAS version 8.0 (SAS Institute 1998) for modeling procedures. We subjected 2-way interactions and main effects appearing in most of the highest-ranking models to a second all-subsets regression. We selected final models by ranking the top 5 models from each subset using Akaike's Information Criterion for small sample sizes (AIC_c; Burnham and Anderson 1998). We then refit the 5 highest-ranking models to the data including area and year as main effect terms. We used a

Wald's χ^2 test and backward elimination to determine whether area and year improved model fit (Agresti 2002).

We collected only 5 of the 12 vegetation variables during phase I, making it necessary to use a limited pool of variables to develop models for the entire 5-year data set (1998–2002). We then fit the highest-ranking models (developed from the limited pool of variables) to data collected only during phase II so that we could make direct comparisons with models developed using the full set of 18 variables. We compared the final models using AIC_c, ΔAIC_c, goodness-of-fit tests (Hosmer and Lemeshow 2000), and the percentage of all nests correctly classified.

Nest Site Location.—We used an analysis of variance (ANOVA) to compare mean VORs, grass heights, forb heights, sagebrush heights, and percent cover for bare ground, grass, forbs, and sagebrush between nest sites and their paired random locations. Because we collected data from paired points on multiple areas and across years, we controlled variance by including the following terms in the model: area, year, area × year, pair (area × year), location, location × area, location × year, and location × area × year. We angular-transformed percent data, and we log-transformed all other variables if means were strongly correlated to variances. We performed final analyses on angular-transformed canopy cover values, log-transformed grass height, and raw data for VOR, forb height, and sagebrush height. We tested all location main effects and interactions against mean squared error. When we found significant interactions, we interpreted simple effects with 2-sample *t*-tests (Zar 1999) taken from within the original ANOVA.

We used Monte Carlo simulations (modified from Manly 1998) to determine whether 6 anthropogenic features impacted nest locations of lesser prairie-chickens. We simulated nest placements by sampling randonly selected points on each area using ArcView 3.1 software (Environmental Systems Research Institute 1992). Each simulated data set consisted of *n* points, where *n* was the number of nests in the area (Area I = 111, Area II = 76). We created 1,000 data sets for each area. For each data set, we computed the distance between each point and the closest version of each feature. Among all random points in a given data set, we selected the shortest distance to each of the 6 types of features. Using the shortest distance from each of the 1,000 data sets, we created distributions of distances from each of the 6 types of features to the nearest random point. We then compared the nearest distance from an observed nest to a feature with the distribution of nearest random points to that particular feature. We computed a *P*-value as the proportion of data sets in which the nearest random point was at least as far away as the nearest observed nest. We repeated this process of distribution construction and *P*-value computation for second-closest nests, third-closest, and so on up to the nearest 10% of nests (Area I = 11, Area II = 8) to each of 6 anthropogenic features. We arbitrarily chose 10% because we assumed birds nesting nearest to a feature were most likely to be affected by it.

Sagebrush Density and Structure.—We derived estimates of sagebrush density (ha^{-1}) for nest sites and paired random sites (2000–2002) using a maximum likelihood estimator for censored distances (adapted from Pollard 1971). We compared density between successful and unsuccessful lesser prairie-chicken nests as well as nest sites and paired random sites. We conducted comparisons between successful and unsuccessful nests with a 1-tailed *Z*-test (Zar 1999). We used 2-tailed *Z*-tests (Zar 1999) to compare the density at nest and random sites. We drew comparisons between sagebrush height and diameter between successful and unsuccessful nests, and nest and random sites using pairwise *t*-tests (Zar 1999).

RESULTS

Nest Success

During our 6-year study, we captured 233 female lesser prairie-chickens, and we fitted 226 with transmitters; we located 209 nests of these transmitter-equipped birds (169 first nests, 35 known renests, and 5 unknowns). Of 209 nests, 118 were on Area I, 84 on Area II, and 7 on neither of the 2 areas. We determined fate of 200 of the 209 nests. Overall apparent nest success was 26.0% (52 of 200) and did not differ across years ($\chi^2 = 6.68$, df = 5, $P = 0.245$). Nest success on Area II was greater in 4 of 5 years in which data were available from both areas, but this difference was not significant in any year (Table 1). However, apparent nest success on Area II (33.3%) was greater (P = 0.028) than success on Area I (18.8%) when we pooled all data (Table 1). Predation by coyotes (*Canis latrans*) and snakes was associated with most unsuccessful nests, but 3 of 148 nests (2.0%) were trampled by cattle (Pitman 2003). Only 4 nests (1.9%) were abandoned.

Table 1. Lesser prairie-chicken apparent nest success (%) on 2 sand-sagebrush prairie areas in southwestern Kansas, USA, 1997–2002.

	Area I			Area II				All nests[b]		
Year	*n*	Success	SE	*n*	Success	SE	*P*[a]	*n*	Success	SE
1997	25	8.0	5.4	0	ND[c]	NA[d]	NT[e]	25	8.0	5.4
1998	14	21.4	11.0	5	60.0	21.9	0.262	19	36.8	11.1
1999	24	37.5	9.9	3	0.0	NA	0.529	29	31.0	8.6
2000	21	9.5	6.4	30	30.0	8.4	0.098	54	22.2	5.7
2001	16	18.8	9.8	24	29.2	9.3	0.711	41	26.8	6.9
2002	12	8.3	8.0	19	42.1	11.3	0.101	32	31.3	8.2
Pooled	112	18.8	3.7	81	33.3	5.2	0.021	200	26.0	3.1

[a] All *P*-values are Fisher's exact test, except pooled nest success, which is a Cochran-Mantel-Haenszel test. The *P*-values resulted from tests to determine whether apparent nest success differed between Area I and Area II.
[b] Includes nests not on either area.
[c] ND = no data.
[d] NA = not applicable.
[e] NT = no test conducted due to insufficient data.

Nest Site Location

Vegetation at Nests and Paired Random Points.—We recorded 5 vegetation measurements (VORs and canopy cover [%] of grass, forb, sagebrush, and bare ground) at 174 lesser prairie-chicken nests and their associated paired random points during both phases of our project. We added 3 additional measurements (sagebrush height, grass height, and forb height) during phase II, and we recorded them at 130 nest sites. We did not find any area or year main effects or interactions for 6 of 8 vegetation measurements allowing for direct interpretation. However, comparisons between forb height and grass height were influenced by area and/or year, and pairwise *t*-tests were necessary to interpret simple effects.

The sand-sagebrush plant nearest to lesser prairie-chicken nests (43.8 ± 1.4 cm) was significantly taller than the nearest sagebrush plant to paired random points (39.0 ± 1.5 cm) (Table 2). Nest sites had greater VORs and sand-sagebrush cover and less bare ground and forb cover than their paired random points (Table 2). Forb height had a significant year × location (nest or random) interaction (Table 2). Comparisons of simple effects indicated that forb height differed between nests (20.0 ± 2.3 cm) and random sites (14.9 ± 2.5 cm) in only 1 of 3 years that we measured it (2002: $t = 3.62$, df = 64, $P < 0.001$). Grass cover was not an important vegetation component in determining nest site location; however, grass height had a significant 3-way interaction (area × year × location; Table 2). On Area I, grass height was only greater at nest sites (11.5 ± 2.7 cm) than random sites (6.5 ± 0.8 cm) in 2002 ($t = 3.39$, df = 24, $P = 0.001$). On Area II, grass height was greater at nest sites (25.0 ± 1.5 cm) than random sites (20.3 ± 1.7 cm) in 2000 ($t = 2.50$, df = 64, $P = 0.014$), but it was less at nest sites (21.8 ± 2.6 cm) than random sites (23.3 ± 2.1 cm) in 2002 ($t = 2.11$, df = 36, $P = 0.040$).

Nest Location and Landscape Features.—Transmission lines, oil and gas wellheads, buildings, improved roads, and center-pivots all influenced nest location on Area I because each nest (in the nearest 10% of the nests to each feature) was far-

Table 2. Mean values for 8 measures of vegetation structure and composition at lesser prairie-chicken nest sites and paired random points in sand-sagebrush prairie of southwestern Kansas, USA, 1998–2002.

	Sampling location					
Vegetation characteristic	Nest (*n* = 174)[a]	SE	Paired random	SE	*F*	*P*
Visual obstruction (dm)	2.4[b]	0.1	1.8	0.1	23.47[c]	<0.001
Sagebrush cover (%)	15.2	1.0	8.2	0.8	24.43	<0.001
Forb cover (%)	8.4	0.6	10.3	0.7	4.55	0.035
Bare ground (%)	37.8	1.8	43.3	1.9	19.65	<0.001
Grass cover (%)	37.2	2.0	36.4	2.0	0.98	0.324
Sagebrush height (cm)	43.8	1.4	39.0	1.5	6.45	0.013
Forb height (cm)	16.3	0.8	14.7	0.9	4.66[d]	0.012
Grass height (cm)	19.2	0.9	17.1	0.8	10.23[e]	<0.001

[a] *n* = 130 for sagebrush height, grass height, and forb height.
[b] Pooled means and standard errors from original data; analyses conducted on angular-transformed variables (sagebrush cover, forb cover, bare ground, grass cover), a log-transformed variable (grass height), and raw data (visual obstruction, sagebrush height, forb height).
[c] Visual obstruction through sagebrush height interpreted from the main effect (sampling location).
[d] Statistics were for a significant year × location interaction.
[e] Statistics were for a significant area × year × location interaction.

Table 3. Monte Carlo simulation tests of distances (m) of the nearest 10% of all lesser prairie-chicken nests to anthropogenic features on 2 sand-sagebrush prairie areas in southwestern Kansas, USA, 1998–2002.

Area - feature	Mean distance from all nests	SE	Nest proximity and distance to feature: 1[a]	8	11	% significant[c]	*n*	NS tests[d]
Area I ($n = 111$)								
Transmission line	1,385	60	263	487	504	100	11	none
Wellhead	588	18	140	265	316	100	11	none
Building	1,951	64	503	984	1,186	100	11	none
Unimproved road	224	13	9	42	50	82	11	2, 6
Improved road	1,526	63	252	680	715	100	11	none
Center-pivots	1,142	40	117	409	524	100	11	none
Area II ($n = 76$)								
Transmission line	1,254	69	144	375	NA[b]	100	8	none
Wellhead	539	27	54	198	NA	0	8	1–8
Building	2,306	53	1,019	1,685	NA	100	8	none
Unimproved road	208	16	11	38	NA	0	8	1–8
Improved road	3,149	202	465	1,095	NA	100	8	none
Center-pivots	977	54	169	347	NA	100	8	none

[a] 1 = closest nest to feature, 2 = second closest nest to feature, and so on.
[b] NA = not applicable.
[c] Percentage of the nearest 10% of nests to each feature that were significantly farther than expected from the feature ($P < 0.05$).
[d] Nest proximities not significantly greater than expected from a feature ($P > 0.05$).

ther from the feature than would be expected at random (Table 3). Additionally, 9 of the 11 observed distances were farther from unimproved roads than would be expected at random. The distance from the nearest nest to each significant feature ranged from 9 m (unimproved road) to 503 m (buildings; Table 3).

On Area II, transmission lines, buildings, improved roads, and center-pivots had significant impacts on lesser prairie-chicken nest locations (Table 3). Of the 76 nests on Area II, the distance from the nearest nest to each significant feature ranged from 144 m (transmission lines) to 1,019 m (buildings; Table 3).

Sagebrush Density and Structure.—Lesser prairie-chicken nests tended to be in dense stands of mature sagebrush. Sagebrush density was greater ($z = 2.98$, $P = 0.001$) at nest sites (pooled estimate = 5,064 ± 240 ha^{-1}) than random sites (4,129 ± 202 ha^{-1}) and was significant in 2 of 3 years (Table 4). Sagebrush plant height and diameter did not differ ($P > 0.10$) between nests and random locations in any year of our study. Sagebrush plant diameter did not differ in 2 of 3 years but was greater at nest sites (84.2 ± 2.7) than random sites (77.3 ± 2.8) in 2001 (Table 4).

Sagebrush plant density was associated with lesser prairie-chicken nest success. Sagebrush density

Table 4. Mean sand-sagebrush density (ha^{-1}) and structure at lesser prairie-chicken nest sites and random sites in southwestern Kansas, USA, 2000–2002.

Year – structure	Nest fate: Successful	SE	Unsuccessful	SE	Use sites: Nest	SE	Random	SE
2000 ($n = 58$)[a]								
Density (ha^{-1})	4,733	768 A[b]	4,256	366 A	4,482	330 A	3,168	250 B
Diameter (cm)	83.7	4.6 A	66.6	2.3 B	71.4	2.0 A	71.9	2.7 A
Height (cm)	47.3	2.2 A	41.1	1.1 B	42.9	0.9 A	43.5	1.1 A
2001 ($n = 42$)[c]								
Density (ha^{-1})	5,646	893 A	6,027	625 A	5,883	467 A	4,927	395 B
Diameter (cm)	91.6	5.9 A	81.0	3.5 B	84.2	2.7 A	77.3	2.8 B
Height (cm)	53.5	2.2 A	47.3	1.7 B	49.2	1.2 A	46.8	1.3 A
2002 ($n = 33$)[d]								
Density (ha^{-1})	4,716	765 A	3,525	404 B	3,985	361 A	4,223	375 A
Diameter (cm)	82.1	4.6 A	69.2	2.7 B	72.6	2.4 A	77.8	2.6 A
Height (cm)	53.3	2.4 A	50.2	2.1 A	51.6	1.5 A	51.1	1.3 A

[a] Forty-three nests were unsuccessful, 12 successful, and the fate of 3 nests was not determined.
[b] Values with different letters differ significantly ($P < 0.10$).
[c] Twenty-six nests were unsuccessful, 11 successful, and the fate of 5 nests was not determined.
[d] Twenty-one nests were unsuccessful, 10 successful, and the fate of 2 nests was not determined.

Table 5. The 5 highest-ranking (based on AIC_c) logistic regression models developed to predict the success of lesser prairie-chicken nests in the sand-sagebrush prairie of southwestern Kansas, USA. Models were developed with 12 vegetation and distance variables measured at 155 lesser prairie-chicken nest sites, 1998–2002.

Model[a,b]	Variables	AIC_c	ΔAIC_c	Correct[c]	Sensitivity[d]	Specificity[e]
−2.111* + 1.357 Vor* − 0.037 Gr* − 0.021 Vor × Shb* −0.068 Vor × Fb* + 0.006 Shb × Fb* + 0.003 Fb × Gr	6	179.100	0.00	58.1	61.9	56.6
−7.174* + 9.178 Vor* + 0.057 Brg* + 5.69E−4 Tld − 0.092 Vor × Shb* − 0.077 Vor × Gr* −0.079 Vor × Brg* − 0.160 Vor × Fb* + 8.27E−3 Shb × Fb* + 0.003 Fb × Gr	9	179.281	0.18	62.6	64.3	61.9
−1.639* +1.467 Vor* − 0.039 Gr* − 9.900E−4 Wd − 0.023 Vor × Shb* − 0.071 Vor × Fb* + 0.006 Shb × Fb* + 0.003 Fb × Gr*	7	180.175	1.08	60.0	66.7	57.5
−2.364* + 1.296 Vor* − 0.037 Gr* + 3.43E−4 Tld − 0.022 Vor × Shb* − 0.066 Vor × Fb* + 0.006 Shb × Fb* + 0.002 Fb × Gr	7	180.367	1.27	58.1	61.9	56.6
− 6.719* + 9.304 Vor* + 0.057 Brg* + 5.87E−4 Tld − 0.001 Wd − 0.094 Vor × Shb*− 0.078 Vor × Gr* − 0.079 Vor × Brg* − 0.162 Vor × Fb* + 0.008 Shb × Fb* + 0.003 Fb × Gr	10	180.488	1.39	61.3	61.9	61.1

[a] Abbreviations for model parameters: Brg = percent bare ground and litter, Fb = percent forb cover, Gr = percent grass cover, Tld = distance to transmission line, Shb = percent sagebrush cover, Vor = visual obstruction, Wd = distance to oil or gas wellhead.
[b] χ^2 tests comparing the − 2 LogL to the model with no covariates were significant for all models ($P < 0.05$) and goodness-of-fit tests (Hosmer and Lemeshow 2000) showed no significant ($P > 0.05$) lack of fit for any of the models.
[c] Percentage of all responses that were predicted with prior probability of 0.26.
[d] Percentage of all successful nests that were predicted correctly using a prior probability of 0.26.
[e] Percentage of all unsuccessful nests that were predicted correctly using a prior probability of 0.26.
*$P \leq 0.05$ for χ^2 test of model parameter.

was greater ($z = 1.53$, $P = 0.063$) at successful nests (pooled estimate = 5,680 ± 534 ha^{-1}) than unsuccessful nests (4,762 ± 275 ha^{-1}), but it was significant in only 1 of 3 years (Table 4). Overall mean sagebrush diameter was greater at successful nests (85.9 ± 3.1 cm) than unsuccessful nests (72.8 ± 3.1 cm); this difference was consistent among years (all $P < 0.01$). In 2 of 3 years, mean sagebrush height at successful nests (pooled estimate = 51.4 ± 1.3 cm) was greater ($P < 0.01$) than at unsuccessful nests (45.8 ± 1.7 cm; Table 4).

Modeling Nest Success

We developed logistic regression models to predict nest success using vegetation measurements and distance to anthropogenic features. We measured only 5 vegetation variables during phase I; therefore, we modeled all nests from phase I and II ($n = 155$) using only those 5 variables and each nest's proximity to 6 anthropogenic features. The 5 highest-ranking models included 6 to 10 variables with VOR, grass cover, shrub cover, and forb cover being included most often (Table 5). Using a prior probability of 0.26 (observed nest success of our lesser prairie-chickens) the highest-ranking model was capable of correctly classifying the success of only 58.1% of the nests (Table 5).

We used 12 vegetation variables and nest distance to 6 anthropogenic features to predict the success of 118 nests located during phase II. The 5 highest-ranking models included 7 to 12 variables (Table 6). The most commonly selected variables were height of sand-sagebrush, density of sand-sagebrush, forb cover, grass cover, grass height, and distance to unimproved roads, transmission lines, and center-pivots. Correct classification of nest success was 74.6% for the highest-ranking model (Table 6). Fit of the highest-ranking model was not improved with the addition of year ($\chi^2 = 0.54$, df = 2, $P = 0.763$) or area ($\chi^2 = 2.62$, df = 1, $P = 0.106$).

We ran models that we derived using the limited pool of variables (phase I and II data) on only the phase II data. Correct classification of nest success by the highest-ranking model developed with the complete set of variables (74.6%) was 11.9 percentage points higher than the highest-ranking model developed with the limited pool of variables (62.7%). The highest-ranking complete model also fit the data better than did the highest-ranking limited model ($\Delta AIC_c = 14.44$). Of the 7 additional vegetation variables used to develop the complete models, 3 (grass height, sagebrush density, sagebrush height) appeared in

Table 6. The 5 highest-ranking (based on AIC_c) logistic regression models developed to predict the success of lesser prairie-chicken nests in the sand-sagebrush prairie of southwestern Kansas, USA. Models were developed with 18 vegetation and distance variables measured at 118 lesser prairie-chicken nest sites, 2000–2002.

Model[a, b]	Variables	AIC_c	ΔAIC_c	Correct[c]	Sensitivity[d]	Specificity[e]
−1.546 + 3.820E−4 Sht² + 3.591E−8 Pd²* − 5.00E−5 FB × Pd* − 0.006 Fb × Gr* + 0.012 Fb × Ght*+ 6.819E−6 Tld × Urd* − 1.100E −6 Tld × Cpd* − 3.610E−6 Urd × Bd*	8	113.620	0.00	74.6	65.5	77.5
− 0.837 + 3.761E−8 Pd²* − 5.00E−5 Fb × Pd − 6.64E−3 Fb × Gr* +0.012 Fb × Ght* + 6.988E−6 Tld × Urd* − 1.08E−6 Tld × Cpd* − 3.640E−6 Urd × Bd*	7	114.321	0.71	74.6	69.0	76.4
−5.561 + 0.100 Pht* + 1.479E−7 Pd²* − 4.00E−5 Fb × Pd* −2.00E−5 Pht × Pd* + 0.008 Shb × Fb* − 0.002 Shb × Gr + 0.003 Fht × Ght* + 5.73E−6 Tld × Urd* − 7.18E−6 Urd × Cpd*	9	114.768	1.15	72.9	69.0	74.2
−1.662 + 3.42E−4 Sht² + 3.29E−8 Pd²* −4.00E−5 Fb × Pd* −0.007 Fb × Gr* + 0.010 Fb × Ght* + 0.001 Fht × Ght +7.126E−6 Tld × Urd* −1.130E−6 Tld × Cpd* − 3.790E−6 Urd × Bd*	9	114.785	1.17	72.0	62.1	75.3
1.213 + 0.020 Ohc − 0.427 Ght* + 1.55E−7 Pd²* − 4.00E−5 Fb × Pd − 2.00E−5 Pht × Pd − 0.001 Shb × Gr − 0.008 Fb × Gr* + 0.011 Fb × Ght* + 0.003 Fht × Ght + 0.006 Ght × Pht + 5.798E−6 Tld × Urd* − 7.490E−6 Urd × Cpd*	12	114.873	1.26	75.4	65.5	78.7

[a] Abbreviations for model parameters: Cpd = distance to center–pivot, Fb = percent forb cover, Fht = forb height, Ght = grass height, Gr = percent grass cover, Ohc = overhead cover, Pd = pasture sagebrush density, Pd² = (pasture sagebrush density)², Pht = pasture sagebrush height, Tld = distance to transmission line, Shb = percent sagebrush cover, Sht² = (sagebrush height)², Bd = distance to building, Urd = distance to unimproved road.

[b] χ^2 tests comparing the − 2 LogL to the model with no covariates were significant for all models ($P < 0.05$) and goodness-of-fit tests (Hosmer and Lemeshow 2000) showed no significant ($P > 0.05$) lack of fit for any of the models.

[c] Percentage of all responses that were predicted with prior probability of 0.26.

[d] Percentage of all successful nests that were predicted correctly using a prior probability of 0.26.

[e] Percentage of all unsuccessful nests that were predicted correctly using a prior probability of 0.26.

*$P \leq 0.05$ for χ^2 test of model parameter.

4 of the 5 highest-ranking complete models. When we developed models describing lesser prairie-chicken nest success without these 3 variables, the percentage of nests correctly classified was lessened considerably.

DISCUSSION

Our major findings were 3-fold: (1) lesser prairie-chicken females selected specific vegetation for nest sites, (2) anthropogenic features were also important in determining nest locations, and (3) nest success was best predicted by the interaction of vegetation (at nest sites) and distance to anthropogenic features. We believe researcher influence on nesting activity was minimal during our study and that our results are representative for lesser prairie-chickens nesting in sand-sagebrush prairie habitat. Our efforts to minimize researcher influence on nest abandonment and predation (Westemeier et al. 1998) produced an estimate of nest success (26%) comparable to rates reported throughout the species' range (Giesen 1998). As evidence of our minimal influence on nesting activity, nest abandonment during our study (2%) was relatively low compared to other reports (25%, Riley et al. 1992). Additionally, predation events typically occurred several days after our initial nest visit ($\bar{x}$ = 10.2 days, SE = 0.73), indicating predators were not attracted to nests by human scent.

During most years, lesser prairie-chickens in southwestern Kansas nested in areas with greater sagebrush density and cover, taller vegetation (grass, forbs, and sagebrush), and less bare ground than surrounding rangeland. On average, lesser prairie-chicken nest sites in southwestern Kansas had greater sagebrush density (5,064 ha^{-1}), sagebrush cover (15%), grass cover (37%), forb cover (8%), and less bare ground (38%) than nest sites in sand-sagebrush habitats of Colorado (Giesen 1994). Location and success of nests in southwestern Kansas were strongly associated with sagebrush plant density and structure, with most successful nests being located in dense stands (>6,500 plants ha^{-1}) of mature sagebrush. Such structure can provide thermal cover during incubation, protection from predators and may function at both fine (nest site) and broad scales (pasture or study area). Long-term population stability has been associated with landscapes composed of greater sagebrush cover than that of landscapes where populations had declined (Woodward et al. 2001). Although grass cover has been shown to be important to lesser prairie-chickens nesting in shinnery oak rangelands (Haukos and Smith 1989, Riley et al. 1992), we did not find this association in sand-sagebrush prairie of southwestern Kansas.

Of 6 anthropogenic features we evaluated, buildings had the greatest impact on lesser prairie-chicken nest locations. Buildings on our study areas consisted of 3 houses, 2 gas compressor stations, and a coal-fired power plant. We did not attempt to distinguish among the impacts of the different structures. We concede that the impact of a house may not equal that of the power plant; however, we did not have multiple units of each for analysis. A nonstatistical review of the nest location data suggests that the impact of houses extended to a radius of 0.5 km, whereas that of compressor stations and the power plant extended to over 1 km.

Impacts of unimproved roads and wellheads on lesser prairie-chicken nest locations were not clear because each feature significantly influenced nest location only on Area I. Although distance to unimproved roads was statistically significant on Area I, influence of this feature on nest location was minimal because nests were located as close as 9 m. We speculate that the negative influence of wellheads could have been evident only on Area I due to topography, different sizes of pump jacks, or noise levels associated with different types of pump motors. If female lesser prairie-chickens reacted negatively to the vertical motion of pump jacks, the slightly more level topography of Area I might have increased negative effects of wellheads relative to more undulating terrain on Area II.

Center-pivots impacted locations of nests on Area I and II. Center-pivot fields were generally bare or had little vegetation present before irrigation began in late April or early May, and these conditions may have deterred females from nesting near these fields. Alternatively, the amount of irrigated field edge, area of fields, movement of irrigation booms rotating across fields, or noise of the irrigation pump in the center of the field might have deterred lesser prairie-chickens from nesting near center-pivot fields.

We seldom found lesser prairie-chicken nests within 400 m of transmission lines or improved roads, even though sand-sagebrush prairie near these features appeared similar to the surrounding area. Transmission lines could pose a threat to nesting lesser prairie-chickens if pylons serve as perches for raptors. Alternatively, noise associated with constant humming of transmission lines carrying high-voltage loads or heavy traffic on improved roads may have deterred nesting females. Negative effects of improved roads have been documented for passerines (Ingelfinger 2001) but not for nest locations of lesser prairie-chickens.

The presence of anthropogenic features effectively eliminated 7,114 ha (53%) of nesting habitat from our 13,380 ha study areas. We speculate that noise may have contributed to lesser prairie-chicken avoidance of buildings, transmission lines, wellheads, center-pivots, and improved roads. Sound levels 100 m from center-pivots ranged from 60–80 db, those from compressor stations were 80–100 db, and the sound level 100 m from the power plant was >100 db when precipitators and scrubbers were operating. Low frequency sounds were easily audible from transmission lines, and heavy traffic on improved roads was commonly heard at >2 km. The height of the anthropogenic features on our study areas also could have deterred nesting activity as prairie-chickens generally have a low tolerance for tall structures (Anderson 1969). Center-pivot irrigation systems had 4- to 5-m high irrigation booms, transmission lines were supported by 30-m high pylons, and gas compressor stations were 1-story buildings served by high voltage lines. The power plant had a 140-m high stack and the coal supply was maintained by a conveyor belt from coal trains to the top of the 30-m high pile.

In our study, lesser prairie-chicken nest success could not be correctly classified using only distance-to-edge data, but distances to unimproved roads, transmission lines, buildings, and center-pivot fields increased predictability of nest success when combined with vegetation characteristics (see also Horkel et al. 1978, Lutz et al. 1994, McKee et al. 1998). What little effect distance from anthropogenic features had on nest success of lesser prairie-chickens may have been associated with predator behavior (Kuehl and Clark 2002). In particular, unimproved roads, transmission line right-of-ways, and field edges may have served as predator travel lanes, and debris around buildings may have provided foraging sites for predators.

Because our method of modeling nest success was an exploratory analysis and the models were not tested on an independent data set, the resulting statistics are likely upward-biased estimates of the true probabilities in each case. Future research that focuses on validating our models with independent data would be useful in determining if variables we identified are causally associated with success of lesser prairie-chicken nests in sand-sagebrush habitats. Additional research is also needed to determine why lesser prairie-chickens did not nest near the anthropogenic features we evaluated. This knowledge may allow modification of those features to reduce impacts on nest placement by lesser prairie-chickens, and possibly other prairie grouse.

MANAGEMENT IMPLICATIONS

To increase nest success in sand-sagebrush prairie habitat, VORs should average >2.7 dm, and sand-sagebrush should be >6,500 mature plants ha^{-1} (18–20% cover). Grazing should be maintained at a level that provides grass height >25 cm during the early spring nesting season. Existing lesser prairie-chicken nesting habitat should be protected from development as the presence of buildings, improved roads, transmission lines, center-pivot fields, and wellheads reduce potential nesting habitat for a radius of up to 1 km. If it is necessary to construct any of these anthropogenic features on known nesting habitat of lesser prairie-chickens, impacts might be lessened if the features are located in areas already compromised (i.e., along improved roads, near existing buildings). Efforts to purchase or obtain long-term land, mineral, and oil conservation leases of sand-sagebrush prairie to benefit lesser prairie-chickens should give priority to areas without the anthropogenic features we evaluated.

ACKNOWLEDGMENTS

Property access was provided by the J.O. Cattle Company, Sunflower Electric Power Corporation, Thornton Cattle Company, Brookover Cattle Company, R. A. Greathouse, and the P. E. Beach family. B. E. Jamison, G. C. Salter, and T. L. Walker Jr. assisted with fieldwork. Our study was supported by Kansas State University (KSU) Division of Biology; KSU Agricultural Experiment Station (Contribution 04-114-J), Kansas Department of Wildlife and Parks, Federal Aid in Wildlife Restoration Grants W-47-R and W-53-R, and Westar Energy, Incorporated. Comments from M. J. Wisdom and an anonymous reviewer enhanced the quality of this manuscript.

LITERATURE CITED

AGRESTI, A. 2002. Categorical data analysis. Second edition. John Wiley and Sons, New York, USA.

ANDERSON, R. K. 1969. Prairie chicken responses to changing booming-ground cover type and height. Journal of Wildlife Management 33:636–643.

BRAUN, C. E., K. MARTIN, T. E. REMINGTON, AND J. R. YOUNG. 1994. North American grouse: issues and strategies for the 21st century. Fifty-ninth North American Wildlife and Natural Resources Conference 59:428–437.

BURNHAM, K. P., AND D. R. ANDERSON. 1998. Model selection and inference: a practical information–theoretic approach. Springer, New York, USA.

COTTAM, G., AND J. T. CURTIS. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451–460.

DAUBENMIRE, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43–64.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. 1992. ArcView GIS version 3.1 user's guide. Environmental Systems Research Institute, Redlands, California, USA.

GIESEN, K. M. 1994. Movements and nesting habitat of lesser prairie chicken hens in Colorado. Southwestern Naturalist 39:95–98.

———. 1998. Lesser prairie-chicken (*Tympanuchus pallidicinctus*). Number 364 *in* F. Gill and A. Poole, editors. The Birds of North America. The Birds of North America, Philadelphia, Pennsylvania, USA.

HAGEN, C. A. 2003. A demographic analysis of lesser prairie-chicken populations in southwestern Kansas: survival, population viability, and habitat use. Dissertation, Kansas State University, Manhattan, USA.

HAUKOS, D. A., AND L. M. SMITH. 1989. Lesser prairie-chicken nest site selection and vegetation characteristics in tebuthiuron-treated and untreated sand shinnery oak in Texas. Great Basin Naturalist 49:624–626.

———, ———, AND G. S. BRODA. 1990. Spring trapping of lesser prairie chickens. Journal of Field Ornithology 61:20–25.

HORKEL, J. D., R. S. LUTZ, AND N. J. SILVY. 1978. The influence of environmental parameters on nesting success of upland game birds. Proceeding of the Annual Conference of the Southeastern Association of Fish and Game Commissions 32:234–241.

HOSMER, D. W. JR., AND S. LEMESHOW. 2000. Applied logistic regression. John Wiley and Sons, New York, USA.

HULETT, G. K., J. R. TOMELLERI, AND C. O. HAMPTON. 1988. Vegetation and flora of a sandsage prairie site in Finney County, southwestern Kansas. Transactions of the Kansas Academy of Science 91:83–95.

INGELFINGER, F. M. 2001. The effects of natural gas development on sagebrush steppe passerines in Sublette County, Wyoming. Thesis, University of Wyoming, Laramie, USA.

JENSEN, W. E., D. A. ROBINSON JR., AND R. D. APPLEGATE. 2000. Distribution and population trend of lesser prairie-chicken in Kansas. Prairie Naturalist 32:169–175.

KUEHL, A. K., AND W. R. CLARK. 2002. Predator activity related to landscape features in northern Iowa. Journal of Wildlife Management 66:1224–1234.

LUTZ, R. S., J. S. LAWRENCE, AND N. J. SILVY. 1994. Nesting ecology of Attwater's prairie-chicken. Journal of Wildlife Management 58:230–233.

LYON, A. G., AND S. H. ANDERSON. 2003. Potential gas development impacts on sage grouse nest initiation and movement. Wildlife Society Bulletin 31:486–491.

MANLY, B. F. J. 1998. Randomization, bootstrap and Monte Carlo methods in biology. Chapman and Hall, London, United Kingdom.

MCGREGOR, R. L., R. E. BROOKS, AND L. A. HAUSER. 1976. Checklist of Kansas vascular plants. State Biological Survey. Kansas Technical Publication 2:1–168.

MCKEE, G., M. R. RYAN, AND L. M. MECHLIN. 1998. Predicting greater prairie-chicken nest success from vegetation and landscape characteristics. Journal of Wildlife Management 62:314–321.

PETERSON, M. J., AND N. J. SILVY. 1996. Reproductive stages limiting productivity of the endangered Attwater's prairie chicken. Conservation Biology 10:1264–1276.

PITMAN, J. C. 2003. Lesser prairie-chicken nest site selection and nest success, juvenile gender determination and growth, and juvenile survival and dispersal in southwestern Kansas. Thesis, Kansas State University, Manhattan, USA.

POLLARD, J. H. 1971. On distance estimators of density in randomly distributed forests. Biometrics 27:991–1002.

RILEY, T. Z., C. A. DAVIS, M. ORTIZ, AND M. J. WISDOM. 1992. Vegetative characteristics of successful and unsuccessful nests of lesser prairie chickens. Journal of Wildlife Management 56:383–387.

ROBEL, R. J., J. N. BRIGGS, A. D. DAYTON, AND L. C. HULBERT. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295–297.

ROERSMA, S. J. 2001. Nesting and brood rearing ecology of plains sharp-tailed grouse (*Tympanuchus phasianellus jamesi*) in a mixed-grass/fescue ecoregion of southern Alberta. Thesis, University of Manitoba, Winnipeg, Canada.

SAS INSTITUTE. 1998. SAS/STAT user's guide, Release 8.0 Edition. SAS Institute, Cary, North Carolina, USA.

SEXSON, M. L. 1980. Destruction of sandsage prairie in southwest Kansas. Proceedings of the North American Prairie Conference 7:113–115.

U.S. CENSUS BUREAU. 2003. State and county quick facts. Finney County, Kansas. <http://quickfacts.census.gov/qfd/states/20/20055.html/>. Accessed 2003 Jan 17.

U.S. DEPARTMENT OF COMMERCE. 2003. National Oceanic and Atmospheric Administration. National Climatic Data Center. <http://www.ncdc.noaa.gov/>. Accessed 2003 Jan 7.

WESTEMEIER, R. L., J. E. BUHNERKEMPE, AND J. D. BRAWN. 1998. Effects of flushing nesting greater prairie-chickens in Illinois. Wilson Bulletin 110:190–197.

WISDOM, M. L., AND L. S. MILLS. 1997. Sensitivity analysis to guide population recovery: prairie-chickens as an example. Journal of Wildlife Management 61:302–312.

WOODWARD, A. J., S. D. FUHLENDORF, D. M. LESLIE, AND J. SHACKFORD. 2001. Influence of landscape composition and change on lesser prairie-chicken (*Tympanuchus pallidinctus*) populations. American Midland Naturalist 145:261–274.

ZAR, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice-Hall, Englewood Cliffs, New Jersey, USA.

Associate Editor: Kelly.